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CHANGES IN THE SPATIAL STRUCTURE OF LAND USE AS A RESULT OF SUBURBANISATION PROCESSES IN RURAL AREAS SURROUNDING THE TRI-CITY AGGLOMERATION

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ABSTRACT

Motives: For many years now, suburbanisation processes have been perceived as one of the most significant factors affecting changes in landscape structures. Numerous attempts are made to find appropriate methods and materials for a comparative analysis of land use changes in different periods of time and other indicators measuring the scale of this phenomenon. These studies result from the need to balance the suburbanisation process around the main service area of the Tri-City, the rapid pace of which causes development to enter areas that are not suitable for development due to environmental reasons. This implies the need for constant monitoring of this process.
Aim: The study is an analysis of changes in land use patterns that took place in some rural areas surrounding the Tri-City agglomeration in the period of 2012–2018, and an attempt to assess how suburbanisation processes may be perceived in the light of the 1985 concept of the Gdańsk agglomeration development. The analysis covers selected rural areas located in the closest vicinity to the central housing zones of the Tri-City agglomeration and areas of rural characteristics located within the administrative borders of the cities.
Results: Applying a synthetic indicator allowing to analyse convergence of structures made it possible to determine areas where the far-reaching changes are observed. The analysis covers some negative consequences of suburbanisation in relation to the natural environment, e.g. the unbalanced proportion between bioactive and built-up areas. In order to grasp current trends, the analysis refers to the data on the agglomeration development in the 1980's. The methods of the research can be used in the analysis of other areas – regardless of administrative borders, for research where statistical data generalized at the commune level are insufficient.

Keywords: suburbanisation, land use changes, indicator of structure convergence, Tri-City, Poland

INTRODUCTION

Suburbanisation processes lead to changes in rural landscape functions and physiognomy through implementation of housing development having sub-urban and urban features. Such processes have negative impact on the natural environment, e.g. the unbalanced proportion between bioactive and built-up areas. New housing zones often emerge in areas of high ecological value. There are four

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basic aspects of urbanization mentioned in the literature: economic (employment, land use), spatial (morphological and physiological changes), social (adapting to the so-called urban way of life) and demographic ones (increasing spatial density and changes in demographic structures) (Jakóbczyk-Gryszkiewicz, 1998; Ziółkowski, 1965). As for the reasons of suburbanisation, there are numerous factors behind it, including:

- searching for more attractive residential areas (the wealthy escape from city centres);
- technological progress (domination of individual modes of transportation on the one hand and possibility to online work from home on the other);
- land rent – lower property prices in the suburbs;
- decentralisation of work places within the metropolitan area (often supported by the administration): trade, industry and service centres are moved to the suburbs and located near transport hubs;
- lack of local development plans or implementing changes to the already existing ones that are beneficial for developers who offer some profit to municipalities (allowing for short-term profits to take precedence over long-term sustainable development);
- lack of coherent spatial policy in cities and metropolitan areas (usually absence of good will to cooperate);
- investors aiming at implementing their development projects in more easily accessible areas, no matter their ecological value (Korwel-Lejkowska, 2020).

Therefore, it may be stated that suburbanisation processes are triggered mainly by socio-economic factors and lack of proper spatial planning. Being aware of how significant are the factors behind suburbanisation processes, their results and methods of analysis, the study presented herein focuses mainly on changes in land use in terms of time and location. These studies result from the need to balance the development of the Tri-City's suburban zone, which, due to its coastal location, cannot expand to the east. The fast pace of suburbanization around the main service area of the Tri-City causes buildings to enter areas that are not suitable for development due to environmental reasons, including valuable natural areas. This implies the need for constant monitoring of this process. This study is an attempt to analyse changes that affected some selected land cover types and to assess how suburbanisation processes may be perceived in the light of the 1985 concept of the Gdańsk agglomeration development. The study covers data for the period of 2012–2018 and its results were compared to the vision of the Gdańsk agglomeration spatial layout prepared in the middle of the 1980's (Przewoźniak, 1985). Moreover, the study is continuation of analyses previously done by the author for the period of 1985–2012 what allowed to determine similarities and differences in ongoing landscape changes. Justifying the need for research, one can refer to the statement that "suburbanization in Poland is an important phase of urbanization. This progressive phenomenon is worth a cyclical study" (Rejter, 2018), but above all, these studies can be used for the sustainable development of the Tri-City suburban area. The use of only statistical data relating to entire administrative units is insufficient – in research in the field of broadly understood spatial management, as well as landscape ecology, there is a need to search for methods combining the use of statistical and geospatial data. The analyzes below follow this trend by proposing to use the structure convergence index. It enables the study of changes in space regardless of administrative boundaries. The presented methods and materials, with their limitations and benefits identified on the basis of the research results, can be used in the analysis of other areas. They constitute a specific method proposition for research for which statistical data generalized at the commune level are insufficient.

LITERATURE REVIEW

The issue of suburbanisation has been a subject of global scientific interest, including the methods of research – especially in relation to the urban sprawl phenomenon (Adamiak et al., 2021; Bosch et al., 2019; Fuladlu et al., 2021; Galster et al., 2001; Lityński, 2021; Mantey & Sudra, 2019; Matuszewska & Będkowski,

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2019) as well as its spatial, economic, demographic, sociological, environmental or political (domestic, regional and local policies) aspects. Some of the published works are reviews – of continental or global range (Antrop, 2004; Dong et al., 2019; Guérois & Pumain, 2008; Güneralp et al., 2020), other focus on a certain issue or region. Both reasons and consequences of suburbanisation vary from one region to another. Among the European studies there are several cases which are worth mentioning: Croatia (Jogun et al., 2017), Spain (Abellán & Ondoño, 2019), Moldova (Sirbu & Cujba, 2020), Germany (Burdack & Hesse, 2007), Romania (Mihai et al., 2015), Slovakia (Repaska et al., 2017) and Hungary (Bagyura, 2020).

Suburbanisation processes are also studied by Polish researchers and there are numerous interesting works including different aspects of the phenomenon, e.g. demographic and economic changes triggered by spatial transformation (Jakóbczyk-Gryszkiewicz, 1998; Rejter, 2018), changes in land cover (Ciesielski & Będkowski, 2014; Polna, 2019; Pukowiec-Kurda & Vavrouchová, 2020) or spatial planning (Ciesielski & Będkowski, 2014; Bieńkowska & Korpetta, 2019; Sobotka, 2015). As concluded Pukowiec-Kurda & Vavrouchová (2020), unplanned and careless introduction of new land cover forms can lead to both the environmental and social degradation of these areas. To prevent this, landscape transformation processes in areas with high dynamics should be constantly monitored. There are also methodological publications in the Polish literature (Staszewska, 2012). One of the problems noticed in the literature is the issue of the availability of statistical data in local research. As rightly stated by Ciesielski and Będkowski (2014), it is not possible to collect information with a greater degree of detail than the commune, which would allow for a more accurate correlation of statistical data with changes in space. Many of the studies relate to administrative units: Rejter (2018), Pukowiec-Kurda and Vavrouchová (2020), Świątkiewicz and team (2021). Usually, it is associated not only with the easier acquisition of statistical data, but also with the spatial policy pursued. However, the different sizes of administrative units in combination with heterogeneous environmental conditions reduce the possibility of a reliable comparison of changes in different areas. The use of small primary fields with the same area allows for a better comparison in this aspect. The method proposed in this article makes it possible to analyze geospatial data in greater detail than a commune.

The most recent works on land cover changes and suburbanisation processes around Tri-City are studies by Czochański (2018), Kistowski (2018), Lorens (2015), Masik (2018), Świątkiewicz and team (2021) as well as the publications by the author of this study (Korwel-Lejkowska, 2016; Korwel-Lejkowska & Nadratowska, 2018; Korwel-Lejkowska, 2020). The work by Lorens (2015), presenting various possible variants of transforming the functional and spatial structure of the Tri-City metropolitan area, draws particular attention. It is a very good study of possible scenarios of urban development pattern as well as with the possible consequences of the these pre-defined scenarios. However, for obvious reasons, this approach is generalized. It is the work on a regional scale, showing schematically the anticipated changes. Moreover, some of the changes that have taken place in the last few years go beyond the forecasted variants. The lack of a detailed approach may be supplemented with studies similar to the ones presented in this article. Nowadays, spatial changes are taking place quickly, yet accessibility to digital data and GIS systems allowing to analyse them is high. However, it should be kept in mind that in central and eastern European countries (Central-East Europe, CEE), including Poland, the pace of landscape transformation has grown significantly since the political transformation that took place at the end of the 20th century. What is more, for many of them becoming a EU member state was an additional driving force of rapid economic development. The study presented herein refers to a concept of the Tri-City agglomeration development (which was called Gdańsk agglomeration at the time) by Przewoźniak (1985) whose recommendations concerning land use are clearly in line with the current sustainable development goals.

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MATERIALS AND METHODS

Research Area

The research area covers the Tri-City agglomeration: Gdańsk, Sopot and Gdynia. The research area is located in northern Poland, in Pomeranian Voivodeship and within the Tri-City Metropolitan Area (Fig. 1). The Tri-City agglomeration (Gdańsk, Gdynia, Sopot) is a vital transportation hub as well as a flourishing cultural and economic centre of this part of the country. According to the physico-geographical regionalisation by Solon et al. (2018), most of the research area is located in the Kashubian Lakeland, with its highest point at 237 m a.s.l. The south-eastern part of the research area stretches over the Vistula delta region (called Żuławy Wiślane) and Sobieszewska Island; the north-eastern part lies within the Kashubian Coast and there is also a small area being part of the Reda-Łeba ice-marginal valley. The edge of the plateau is quite steep and it transforms into a coastal plain. High environmental diversity of the research area seems to predestine it to perform various functions. Having the most fertile soil, the Vistula delta region has the best conditions for agriculture. In the lakelands there are more forests, lakes and river valleys. The soil there is not that fertile and there are less advantageous weather conditions. Therefore, forestry and tourism are the key sectors for this area.

As the Tri-City agglomeration is located along the Gulf of Gdańsk, its development directions are limited, what causes numerous problems, e.g. ones concerning development of the transportation system and increasing investment expansion to other areas. The analysed rural areas are located in close vicinity to the strict agglomeration centre: the eastern border of the research area runs along a densely built-up central service belt, the remaining borders are formed by natural barriers.

Data sources and research methods

In order to analyse the changes in land use, data related to location and area covered by forests, grasslands, waters and buildings in 2012 and 2018 was downloaded from the Topographic Objects Database (BDOT10k). This vector database is appropriate to the topographical maps in the scale 1:10000 what allowed the author to analyse the actual area covered by buildings themselves.

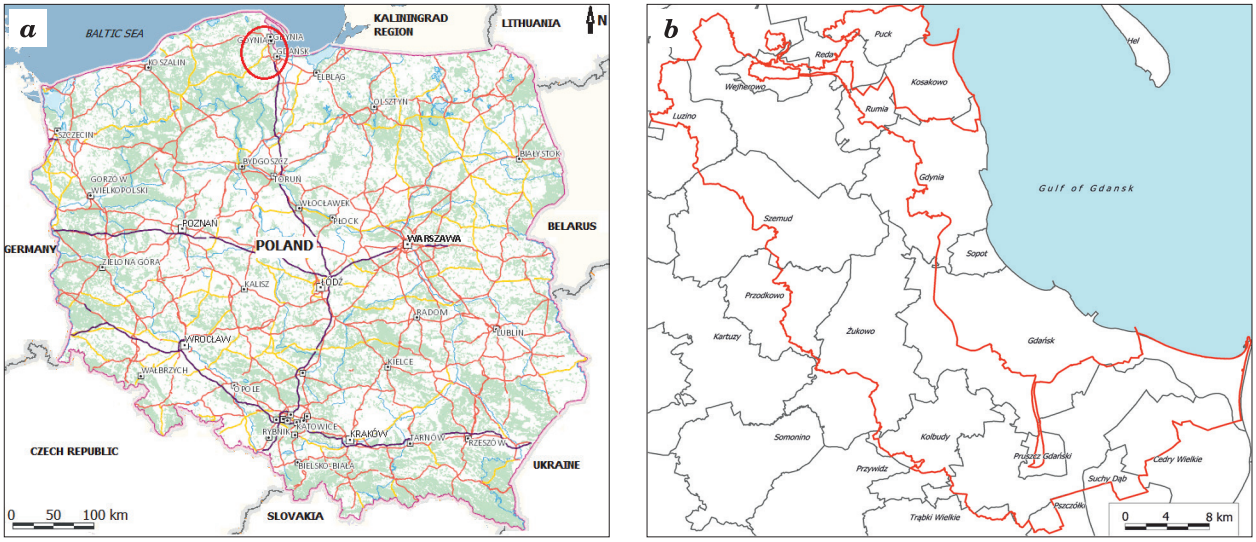

Fig. 1. Location of the research area in Poland and Central Europe (a) and at the background of municipalities of Pomeranian Voivodeship (b)

Source: own preparation based on https://mapy.geoportal.gov.pl/.

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The study takes into account location of the following types of land cover (percentage of the primary field):
- ones that existed at the beginning of the analysed period of time;
- ones that increased their area in the analysed period of time;
- ones that decreased their area in the analysed period of time;
- ones that did not undergo changes in the analysed period of time.

Vector layers for objects that emerged or were eradicated/demolished in the analysed period of time were obtained by superimposing the input vector layers. For the purpose of the analysis the author divided the research area into square primary fields, each covering the area of 0,25 km^2. For each primary field and for the whole research area, changes in the areas covered by forests, grasslands, waters and buildings in 2012 and 2018 were calculated.

Then, in order to indicate areas where the changes in land use were the most advanced in the analysed period, the following indicator of structure convergence was applied (c) (Wiatrak, 1982):

$$c = \cos \propto = \frac{\sum_{j=1}^{m} \overline{W}_{j(t0)} * \overline{W}_{j(t1)}}{\left[\sum_{j=1}^{m} \overline{W^2}_{j(t0)}\right]^{\frac{1}{2}} * \left[\sum_{j=1}^{m} \overline{W^2}_{j(t1)}\right]^{\frac{1}{2}}} \quad (1)$$

where:

$\overline{W}_j$ – branching indicator (the area covered by a certain land cover type within the primary field, divided by the total area of the primary field and multiplied by 100)

The indicator ranges from 0 (turnabout) to 1 (no change). The results were then clustered into six classes on the basis of the main break points on the distribution curve what allowed the author to indicate the areas that underwent the most advanced changes in land use in the analysed period. In the next step, the results were compared with the analyses done for the period of 1985–2012 (Korwel-Lejkowska, 2020) and current directions of spatial changes for the research area were set.

Finally, the analysis results were compared to the 1985 concept of the Gdańsk agglomeration development by Przewoźniak (1985) which includes not only the author's vision of future development directions, but also an analysis of physico-geographical development barriers as well as an in-depth analysis of environmental conditions within the delimited geocomplexes (including part of Łężyce village which was excluded from the Tri-City Landscape Park in 2006 – Regulation No. 57/06). What is more, Przewoźniak determined areas of acceptable urban development. Those areas were compared with the results for the periods of 1985–2012 and 2013–2018. At this stage of the analysis, the author determined 100-metre buffer zones around the new built-up areas. Single buildings having a buffer zone smaller than 5ha were excluded from the analysis as well as cases when there were less than three buildings within the buffer zone.

The GIS analysis was carried out using MapInfo Professional and statistical calculations were done with the use of Microsoft Excel.

RESULTS

Changes of the selected land cover types in the period of 2012–2018

Most of the forest areas did not undergo any changes within the analysed six-year period. Minor increases in the forest cover were observed between Gdynia – Dąbrowa and Chwaszczyno, near Smęgorzyno and in the area north of Kolbudy (restoration started more than 10 years ago). Decreases in the forest cover were recorded in Kępa Oksywska (as a result of construction works when building an airport in Gdynia – Babie Doły), in the *Borowiec Ip* sand and gravel mining area (currently a water reservoir), near Gdańsk-Matarnia (as a result of construction works when building a railway line to Rębiechowo) and Kokoszki (development of the industrial area near the airport), in Łapino and Kolbudy (residential areas development).

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Both, the grasslands and built-up areas have undergone sweeping changes in the last 30 years. In the period of 2012–2018 the percentage of grasslands increased in belts stretching from Gdańsk – Osowa to Przodkowo and from Matarnia to Przywidz what was mainly the result of agricultural abandonment. Some of the above-mentioned areas have been designated for residential development. An increased percentage of grasslands near the Wisła Śmiała (Bold Vistula) mouth and the Vistula Canal is a result of natural processes. However, closer attention was paid to a continuous area located between Wiślina, Wocławy and Grabiny Zameczek that is classified as grasslands in the BDOT10k. The analysis of the 2011–2018 Google Earth ortophotomaps revealed that this area has never been covered by grass. This case may contribute to the debate on the BDOT10k data credibility.

Some decreases in the grassland area resulting from changes in agricultural activities was observed in Moście Błota and in some places located in the Vistula delta region (e.g. near Cieplewo). Some significant decreases in the percentage of grasslands are also observed within a belt surrounding the densely built-up areas of the Tri-City (excluding the forests) and belts stretching south of the Tri-City towards Pruszcz Gdański and southwest of Żukowo. In these cases, the decreases are the result of functional changes, mainly connected with development of the transportation network. However, some of the above-mentioned areas, especially in the central part of the research area, have been undergoing self-afforestation by natural succession. There is also an interesting case of Sobieszewska Island which is another example of incorrect land cover classification in the 2012 BDOT10k data (Korwel-Lejkowska, 2020).

There were almost no changes observed in the percentage of water surface in the analysed region and the minor ones that actually were observed resulted from natural coastal processes and channel processes, mainly concerning the Radunia and Reda rivers. However, some water reservoirs emerged in the centre of the research area, between Tuchom and Borowiec, as a result of mining activities performed by the Polgravel company within the ares of the *Borowiec* sand and gravel deposits.

The changes concerning new buildings constructed in the area in the analysed period may be concerned a perfect example of how suburbanisation processes work. During the six-year period more than 15 thousand buildings, having an average area of 163 m^2, were constructed or enlarged in the research area. At the same time, 5187 objects, having an average area of 93.5 m^2, were demolished – nearly half of them were farm buildings. They used to be located evenly around the Tri-City central service belt with some more densely built-up areas in the southern part of Kosakowo (within the boundaries of the Naval Aeronautical Base), the western (industrial) part of Wejherowo and the south-eastern part of Gdańsk (old farm buildings in Olszynka and Orunia; neglected summer houses in Sobieszewska Island). Table 1 presents areas with the highest percentage of newly built/enlarged residential or industrial objects.

Table 1. Areas with the highest increases in housing/industrial development in the period of 2012-2018

Municipality*	Towns/villages with the highest percentage of newly built/enlarged residential or industrial objects	Main functions of the newly built objects
1	2	3
Cedry Wielkie (r)	Wocławy Miłocin II (south of Koszwały)	production facilities and warehouses
Pruszcz Gdański (u)	along the transport route to Rotmanka	multi-family buildings and large area commercial objects
	north and northeast of the Wschód residential area	common residential zone including single-family detached and terraced houses which has blurred the border between urban and rural areas
	in the south-western part	development of the warehouse-production zone

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cont. Table 1

1	2	3
Pruszcz Gdański (r)	Straszyn-Prędzieszyn Zone	warehouses, commercial objects, single- and multi-family buildings located on slopes of 9° angle (some of them located far from the already existing housing estates)
	Rotmanka	development of multi-family housing estates and terraced houses large area warehouses
	Cieplewo – the southern part	production facilities and warehouses
	in the villages along DK 75, continuing in Pszczółki (Różyny, Kleszczewko)	residential objects (located further and further from the main transport route)
	Mokry Dwór, Wiślina, Wiślinka, Radunica, Rokitnica and Roszkowo	single-family buildings (including the areas located at -0.5 - 2 m above the sea level with shallow ground waters)
Gdańsk (u)	„Wschód" sewage treatment unit	farm buildings
	between DK 89 and DW 501	warehouses
	airport	airport buildings
	near the boudary with Kowale and in Bysewo, Matarnia and Kokoszki	commercial objects and smaller warehouses
	Gdańsk Osowa (district)	large area commercial objects near the hub with the Bypass and multi-family buildings in the southern part of the district
	Klukowo, Smęgorzyno, Kiełpino Górne, Borkowo	scattered single-family buildings
	Kiełpinek, development of Kolorowe Housing Estate, the area between the Cztery Pory Roku Housing Estate and Gdańsk-Maćkowy,	multi-family buildings
	in the belt stretching from Gdańsk-Migowo in the north to the border with Kowale in the south; Ujeścisko and Piastów Housing Estate	the highest percentage of new residential buildings
	along the belt paralel to St. Wojciech Street in Gdańsk-Nowy Port and Gdańsk-Lipce	slightly higher percentage of new buildings (mainly farm and single-family ones)
Kolbudy (r)	Kolbudy, Łapino, Ostróżki, Lisewiec, Otomin, Jankowo Gdańskie, Lublewo, Pręgowo	increasing housing density and scattered single-family buildings (also on the slopes of neighbouring hills, far from transport routes)
	Kowale – west of DK S6	large warehouses, scattered single-family buildings located further from DK S6
	Kowale – east of DK S6, towards Borkowo	commercial objects, multi- and single-family buildings (the existing residential belt hampers wildlife movements, especially near wetlands)
Żukowo (u-r)	Chwaszczyno	single-family buildings further from DW 218 and DK 20; warehouses, farm buildings and production facilities north-west and west of the centre of Chwaszczyno
	between Tuchom and Miszewko	production facilities and warehouses along DK 20
	Tuchom	single-family buildings – increasing the density of the existing housing areas and building some new objects; new Golf Park Housing Estate near Tuchom Lake
	Banino	single-family detached and terraced houses – scattered and located on the former arable lands

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cont. Table 1

1	2	3
	Rębiechowo	single-family buildings, some production facilities near the boundary with the city of Gdańsk
	Pępowo, Małkowo, Czaple, Leźno, Borkowo, Lniska, Niestępowo, Mała Przyjaźń	scattered single-family buildings in the already existing residential area
	Żukowo	single-family buildings with some commercial facilities and an education centre
Przodkowo (r)	Tokary	sports hall;
	Przodkowo	scattered single-family buildings, commercial facilities
Szemud (r)	Bojano	upgrading the existing school sports centre, scattered single-family buildings located on wetlands
Gdynia (u)	Chwarzno	increasing density of the already existing single-family housing areas, farm buildings
	Wiczlino	multi-family buildings
	Wielki Kack and Dąbrowa	production halls, warehouses and a commercial centre
	Enclaves in the forest along Kmd Sakowicza Street	military administration facilities
	Pustki Cisowskie	multi-family buildings and a commercial object
Kosakowo (r)	Dębogórze-Wybudowanie	single-family buildings
	within the boundaries of the military base, south of Suchy Dwór and in Ostrowski Canyon	residential buildings and farm buildings according to the BDOT classification
	Suchy Dwór	single-family buildings
	Pogórze	large area shopping centre, single- and multi-family buildings
	between Pogórze and Kosakowo	school
	Kosakowo	single-family buildings
	Pierwoszyno, Mosty and Mechelinki	increased percentage of single-family buildings
Reda (u)	Reda	large area shopping centre, twelve multi-family buildings located on a steep slope (deforestation)
	Ciechocino	residential areas: mainly single-family buildings; some new farm buildings
	Betlejem	single- and multi-family buildings
Wejherowo (r)	Gościcino	production facilities, farm buildings, service and commercial facilities, warehouses
	Bolszewo	single-family buildings in the existing residential area; multi-family housing estate, commercial and service facilities, a care institution

* u – urban areas, r – rural areas, u-r – urban-rural areas (according to the Eurostat – Local Administrative Units)
Source: own preparation based on the BDOT10k data.

The analysis of structure convergence indicator *c* allowed to indicate eight areas where changes in land use are the most extreme in the whole period of 1985–2018. Five of them are also areas of the most intense changes in the period of 1985–2012 (Korwel-Lejkowska, 2020) and other three were experiencing the most intense transformations after 2012 (Fig. 2). The final analysis did not cover the areas located in the south-eastern part of the research area as they had been incorrectly categorised in the BDOT10k (the assignment of cultivated areas to grasslands).

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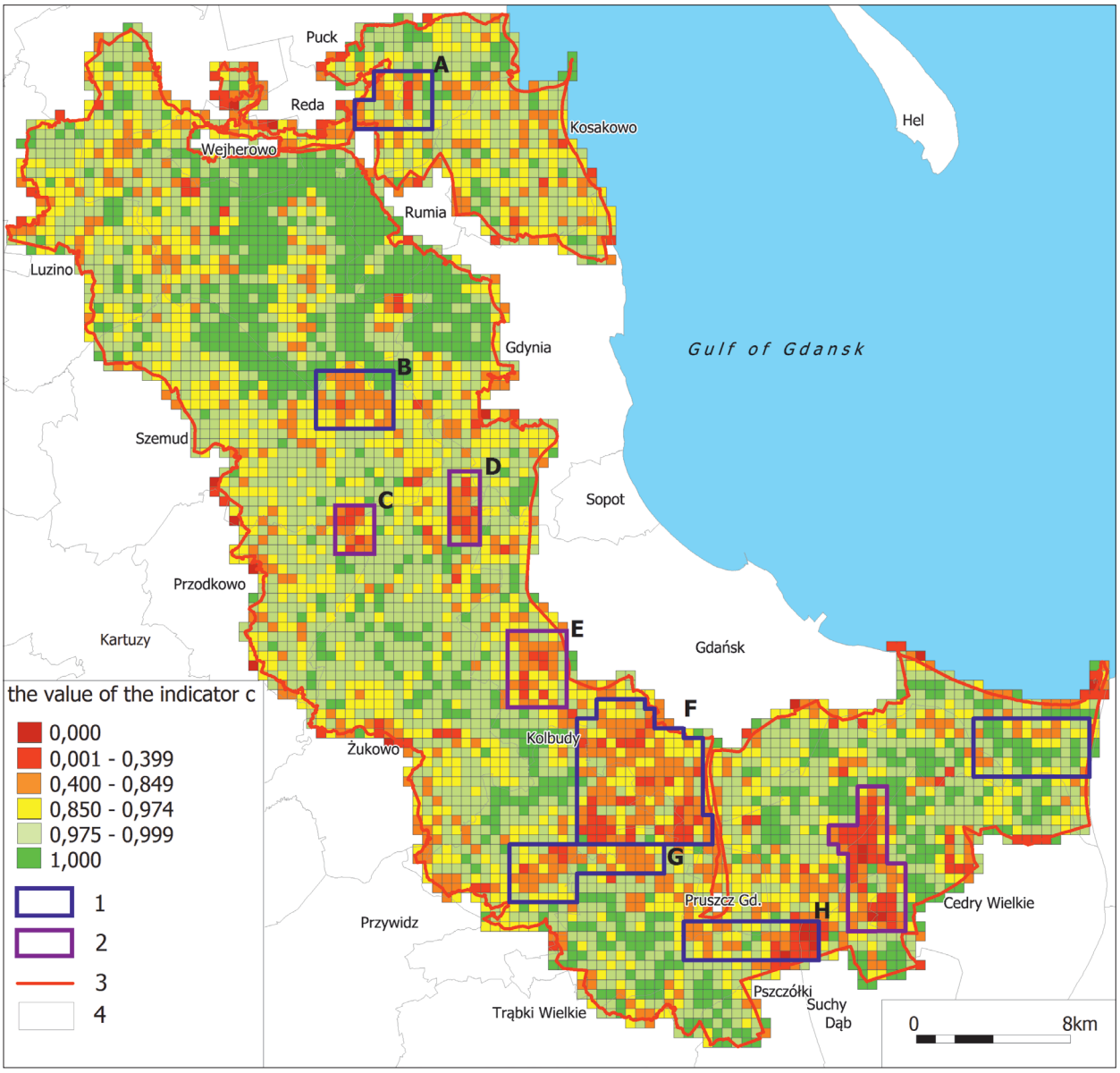

1 – areas of the greatest changes in 1985–2012; 2 – areas of the greatest changes in 2012–2018; 3 – border of the study area; 4 – borders of municipalities;

Fig. 2. Spatial distribution of the „c" indicator and location of the areas where the most intense changes took place in the analysed periods

Source: own preparation based on the BDOT10k data.

The areas where the most advanced changes in land use are observed are as follows:

A. Rekowo (municipalities: Reda and Puck / area of 10.5 km^2) – changes in farming areas, including grasslands, resulting from agricultural activities;

B. Koleczkowo (municipalities: Szemud, Wejherowo and the city of Gdynia / area of 12 km^2) – high dynamics of changes in grassland areas after 2001, a significant increase in residential areas along the main roads and some new holiday housing areas near forests and lakes in Marchowo;

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C. Warzenko (municipalities: Szemud, Przodkowo and Żukowo / area of 5.12 km^2) – area where the most intense changes started after 2012 as a result of agricultural abandonment, set-aside (probably in order to sell the grounds to developers); new housing objects;
D. Kowale – Chwaszczyno (Żukowo municipality, the cities of Gdańsk and Gdynia / area of 6,05 km^2) – area where the most intense changes started after 2012 as a result of large increases in housing and green areas (formerly used for farming);
E. Rębiechowo – Kokoszki (the city of Gdańsk / area of 12.3 km^2) – area where the most intense changes started after 2012 as a result of development of the airport (transport network and service buildings) – new objects are of large area (warehouses and offices) and were constructed, among others, in areas that had undergone deforestation;
F. Gdańsk – Południe (the city of Gdańsk, municipalities: Pruszcz Gdański and Kolbudy / area of 44 km^2) – the observed changes in land use refer to new residential areas in the southern part of Gdańsk: there are some multi-family housing estates in areas where this type of housing already existed and some new housing estates located far away from the main transport routes (up to 300 m) and other residential areas (up to 500 m), sometimes established in the middle of a set-aside field; large area commercial facilities and warehouses along DK S6; 10 enlarged or newly built water retention reservoirs; changes in the percentage of grasslands;
G. Radunia Valley (Kolbudy municipality / area of 17.25 km^2) – most changes were triggered by: construction of new water reservoirs (water retention reservoir in Bielkowo and some smaller reservoirs and ponds), changes in the grassland areas, forest succession, new housing estates – especially in the eastern part of the area (single-family buildings, gated multi-family housing estates);
H. Cieplewo (municipalities: Pruszcz Gdański and Suchy Dąb / area of 14 km^2) – a large industrial-warehouse zone near the border with Pruszcz Gdański and in close vicinity to the main transport routes has been developed for more than 10 years – as a result the percentage of farming and grassland areas has decreased significantly; some small water retention reservoirs were built; new housing estates in Cieplewo; in the eastern part of the area changes in the percentage of farming and grassland areas are the result of agricultural activities.

The currently observed changes are the result of some former processes. When comparing the period of 2012–2018 to the studies done for the earlier periods (Korwel-Lejkowska, 2020), some trends become clearly visible. From 1985 to 2018 the percentage of biologically active areas (understood as a total area of forests, grasslands and waters) increased by more than 10.5 (Table 2). Changes in the ratio of biologically

Table 2. Changes in the land cover structure in the period of 1985–2018

Land cover types	1985		2000		2012		2018	
	ha	%	ha	%	ha	%	ha	%
forests	24533.8	23.58	25373.4	24.39	27423.0	26.36	27393.0	26.33
grasslands	16441.3	15.80	17426.1	16.75	24079.3	23.14	24360.4	23.41
waters	1955.2	1.88	1984.31	1.91	2114.77	2.03	2133.98	2.05
total	42930.3	41.26	44783.8	43.04	53617.07	51.53	53887.38	51.79
built-up land	794.7	0.76	1082.0	1.04	1346.34	1.29	1550.87	1.49
total	43725.1	42.03	45865.8	44.08	54963.41	52.83	55438.25	53.28
other types of land cover	60321.2	57.98	58180.4	55.92	49082.8	47.17	48607.97	46.72

Source: own preparation based on the BDOT10k data.

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active areas to built-up areas are considered an indicator of suburbanisation advancement. In the research area the ratio was 54.02 in 1985 and 34.75 in 2018. Thus, the percentage of built-up areas increased significantly during the analysed period. Yet, the intensity of the process was not always the same in terms of time and location. The pace of urban expansion before 2000 was eight times faster than after 2001. It is also worth mentioning that between 1985 and 2000 its value decreased by 12.63 while during the second analysed period – only by 1.57. This is a result of setting-aside arable lands and afforestation (opportunity to apply for the EU funding) in the period of 2001–2012. However, there are also vast areas where the biologically active area is decreasing leading to negative changes in the natural environment and landscape physiognomy. The analysis revealed that the actual percentage of built-up areas is not high for the whole research area (Table 2). Yet, it has to be remembered that it is a result of the methodology applied as the scale of maps used allowed to sum up the areas actually cover by buildings that are not biologically active. The analysis of changes in the land cover structure indicated clearly that the built-up areas increased by 69% during the analysed period while the grasslands by slightly more than 46%, the forests and waters by approximately 10%. This proves that suburbanisation processes were taking place in the research area in the analysed period.

Suburbanisation in the area surrounding the Tri-City agglomeration: concept from 1985 compared to the actual course of the process

In order to estimate changes that took place in the area surrounding the Tri-City agglomeration from 1985 to 2018, the author referred to the study by Przewoźniak (1985) where a scheme of the Gdańsk agglomeration spatial layout can be found. Przewoźniak indicated development thresholds, suggested sustainable development directions and, what is worth paying special attention, determined areas of high ecological value which should not be intensely developed for housing, commerce, industry, etc. The analysis for the periods of 1985–2012 and 2012–2018 showed that almost all development thresholds were overrun, especially in the northern and south-western part of the research area (Fig. 3). Only the forest on the edge of the Gdańsk Upland has remained relatively untouched as it is now part of the Tri-City Landscape Park. However, there are more and more roads running through the park and leading to some new housing estates. The development belts westward that were suggested by Przewoźniak have been replaced by massive urban sprawl towards farming areas in the northern and southern parts of the research area and towards multi-functional open spaces (sometimes even protected areas).

Change in the land cover structure (%) during the analysed period					Change in the land cover structure (%) in relations to the first year of the analysed period				
1985–2000	2001–2012	1985–2012	1985–2018	2012–2018	1985–2000	2001–2012	1985–2012	1985–2018	2012–2018
0.81	1.97	2.78	2.75	-0.03	3.42	8.08	11.78	11.65	-0.11
0.95	6.39	7.34	7.61	0.27	5.99	38.18	46.46	48.17	1.17
0.03	0.13	0.15	0.17	0.02	1.49	6.58	8.16	9.14	0.91
1.78	8.49	10.27	10.53	0.26	4.32	19.72	24.89	25.52	0.50
0.28	0.25	0.53	0.73	0.20	36.15	24.43	69.41	95.14	15.19
2.06	8.74	10.80	11.26	0.46	4.90	19.84	25.70	26.79	0.86
-2.06	-8.74	-10.80	-11.26	-0.46	-3.55	-15.64	-18.63	-19.42	-0.97

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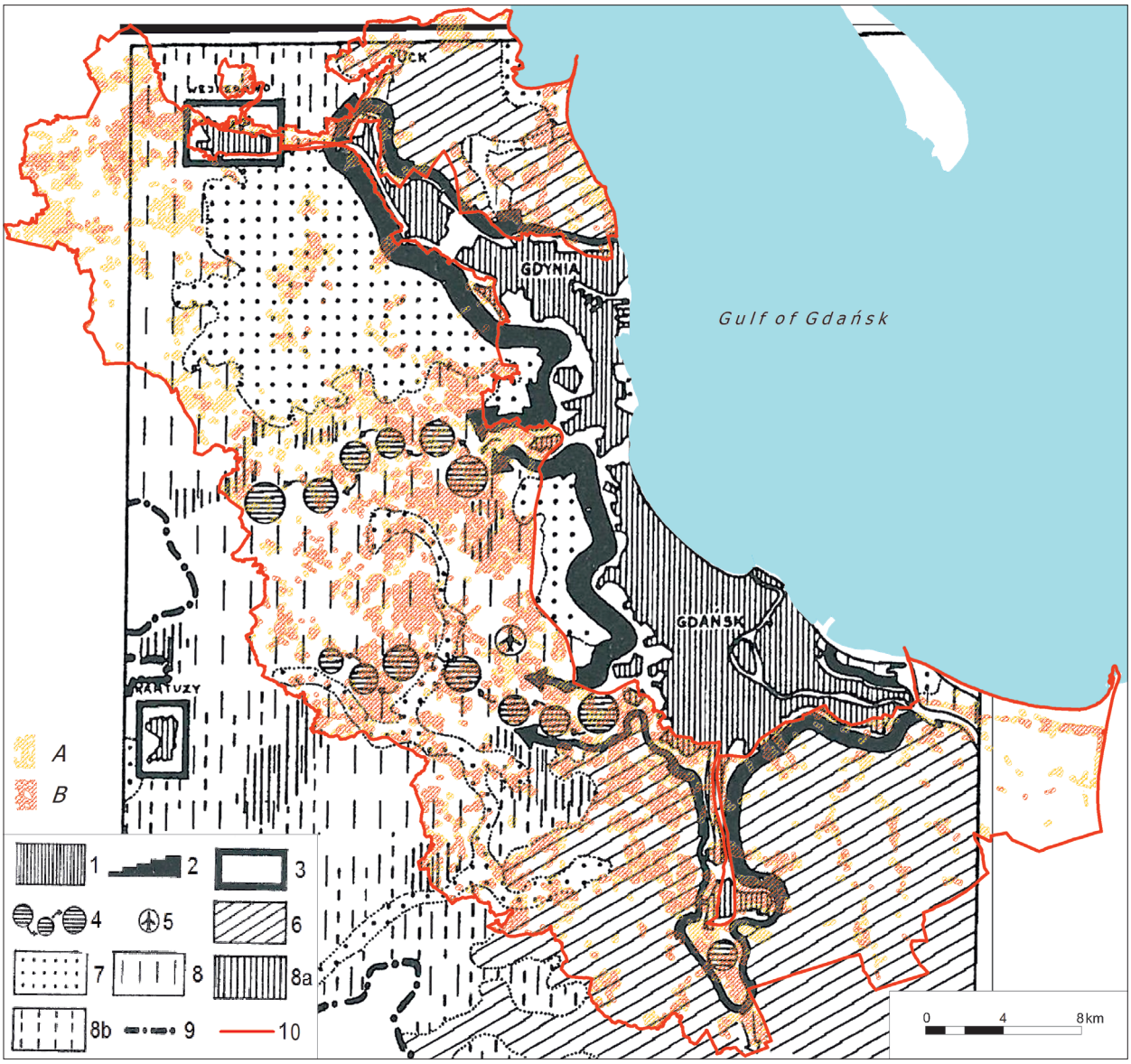

A – buffer zones of the housing estates built in the period of 1985–2012; B – buffer zones of the housing estates built in the period of 2012–2018; 1 – built-up urban areas; 2 – development thresholds with a growing number of development barriers; 3 – areas with no spatial development perspectives; 4 – suggested urban belts; 5 – airport; 6 – areas of intensive farming; 7 – preserved areas; 8 – multi-functional open spaces: 8a – leisure areas, 8b – forest stands; 9 – border of „the agglomeration natural area"; 10 – border of the study;

Fig. 3. Comparison of the distribution of buildings erected in the period of 1985-2018 and the 1985 scheme of the Gdańsk agglomeration spatial layout by Przewoźniak

Source: own preparation based on Przewoźniak (1985).

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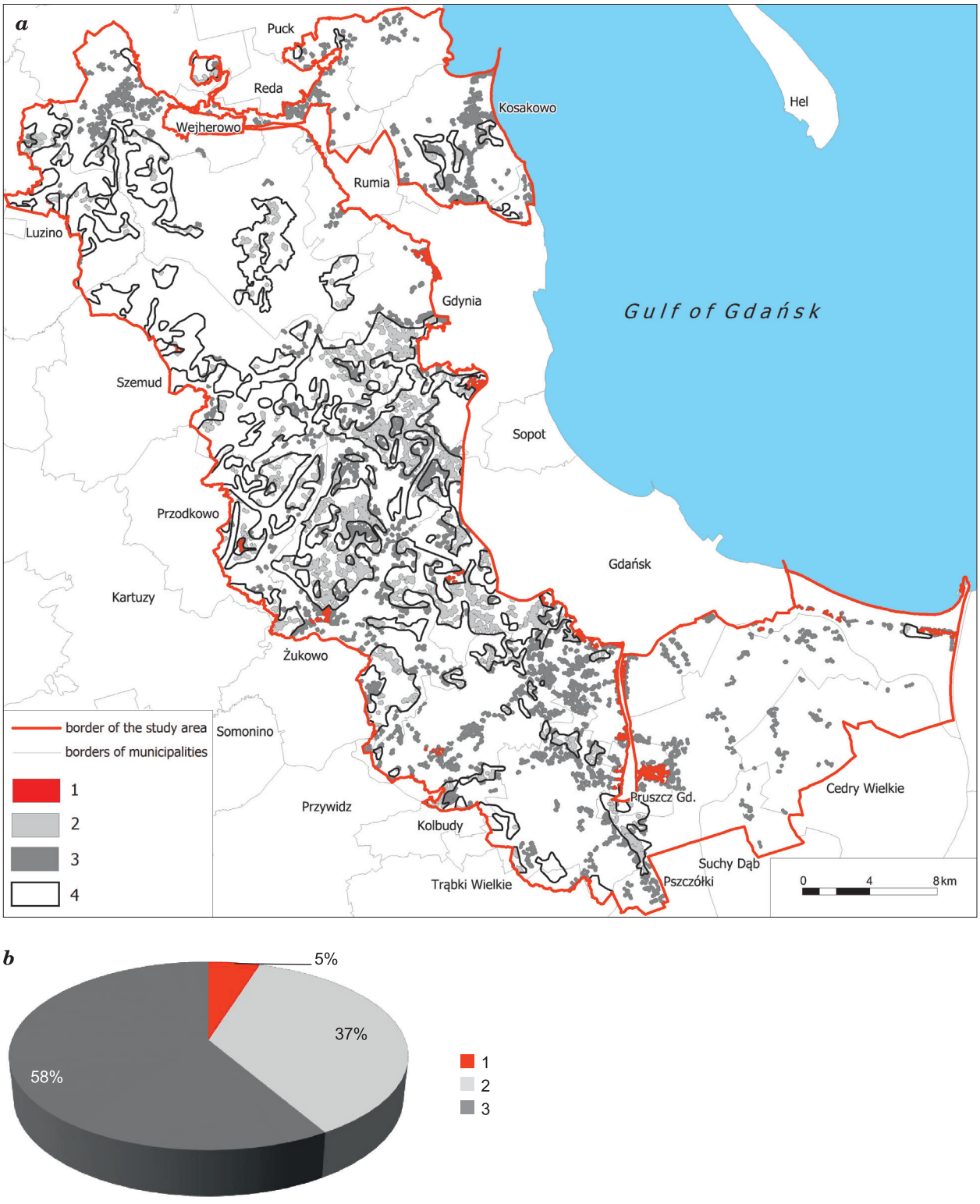

1 – existing built-up areas where some new development projects were implemented, increasing the density of buildings; 2 – buffers created by buildings constructed within the areas of acceptable urban development; 3 – buffers created by buildings constructed outside the areas of acceptable urban development; 4 – areas of acceptable urban development

Fig. 4. Location (a) and structure (b) of buildings constructed in the period of 2012–2018 (in a form of buffers) in relations to the areas of the acceptable urban development by Przewoźniak

Source: own preparation based on Przewoźniak (1985).

Negative changes observed in the areas surrounding the Tri-City agglomeration are even more visible when compared to the suggested directions of landscape management. Przewoźniak determined these directions on the basis of:
- geocomplexes conditioning functional balance of landscape (they are areas having great impact on humidity and water conditions as well as areas vulnerable to erosion processes);
- geocomplexes of high productivity – having fertile soils;
- geocomplexes of acceptable urban development which were analysed in the last stage of this study.

The analysis of spatial distribution of the built-up areas in the period of 2012–2018 in relation to the areas of acceptable urban development suggested by Przewoźniak (Fig. 4) revealed that 6183.1 ha of new built-up areas were established within such areas and 9853.6 ha outside of them, in the areas predestined to perform other functions. The remaining new residential areas were established within the borders of the already existing settlement units (824.2 ha).

DISCUSSION

Suburbanisation is a significant issue which has been studied using different research methods. The methodology applied to the study presented herein allowed the author to indicate exact places where spatial changes took place in the analysed period, no matter the administrative borders. The BDOT10k is very useful for local and regional studies, e.g. for a single municipality, like in the study by Matuszewska and Będkowski (2019). However, when analysing the BDOT10k data, one should have some knowledge of the analysed area as this data base is not free from categorisation mistakes, especially concerning grasslands and different stages of forest development. A limitation for retrospective analyzes may be the availability of land cover data, mainly related to the year of publication of topographic maps or aerial photographs. Currently, for many years the availability of digital data has been improving year by year, which eliminates the previous problem. Therefore, it is advisable to compare the BDOT10k data with another source, e.g. satellite and aerial photos which can be downloaded from *Corine Land Cover* (CLC), what has also been confirmed in the studies by Ciesielski and Będkowski (2014), Matuszewska and Będkowski (2019), Pukowiec-Kurda and Vavrouchová (2020). For the area of Poland, BDOT10k or CLC data are a good source. For areas of other countries – CLC coverage or data from individual countries' resources are recommended. When conducting research for areas located in various countries, it is important to use a unified database or data closest in terms of the scale and detail of mapping.

The process of urban sprawl usually affects the structure of land cover types in a particular area. Thus, a comprehensive approach should be applied in order to evaluate spatial changes it brings. For the purpose of this study, the author analyse – apart from the buildings – changes in the area of forests, grasslands and waters. Having sufficient knowledge on the research area, the author was able to generalise some land cover types, e.g. orchards and plantations that cover a relatively minor percentage of the research area and did not undergo any significant changes during the research period. When analysing larger areas with the use of the CLC data, the number of land cover types is much bigger (using CLC allows the analysis land changes on a regional scale), yet this data base is not free from classification errors. That is why using some older studies, based on numerous cartographic sources and fieldwork research, is strongly advisable. The study by Przewoźniak (1985) is a good example of such works and may be used as a proper reference for spatial analyses. The process of urban sprawl in the areas surrounding the Tri-City agglomeration is so advanced that new buildings are constructed in areas with physio-technical, biological, topographic and climatic constrains (the Vistula delta region, the Reda-Łeba ice-marginal valley), in areas that should perform agricultural function (fertile soils) or should be left as bioactive in order to maintain functional balance of the environment. The investment-related pressure in the uplands has caused a significant

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increase in the impermeable surface area. As a result, flooding and water accumulation are recurring problems in Gdańsk. Lack of the urban belts along the main transportation routes (as suggested by Przewoźniak) results in constant problems, which are as follows: insufficient accessibility by the means of public transportation (costly and time-consuming daily private commuting); air pollution caused by an insufficient system of individual heating; a decreasing percentage of green areas (including public leisure areas) and negative changes in landscape (lack of local development plans). At the same time, the newly built infrastructure is often damaged by flooding or land sliding because it has been constructed in areas where physiographic and technical constraints had been identified yet not taken under consideration. To sum up, in line with the assumed goal, the changes in selected land cover forms in 2012–2018 were analyzed and the places of the greatest changes (taken collectively) in the landscape were pointed out. Areas which have been undergoing intensive changes for many years, as well as new places to pay attention to in order to monitor changes have been identified. At the same time, the location was identified and the scale of new buildings erected in areas not recommended for investment due to environmental conditions (according to Przewoźniak [1985]) was estimated. The tested index of structure convergence can be recommended as a tool for other research.

As the analyzes have shown, the use of the structure convergence index (c) and the geometric grid of basic fields allows for conducting the research at a very detailed level. For comparison, in works based on schematics (e.g. connections in the landscape, directions of development, etc.), as in the work of Lorens (2015), it is not possible to obtain information about specific places of changes or conflicts. In article about urban development scenarios of the Tri-City Metropolitan Area (Lorens, 2015) the economic, political, social and communication implications are mentioned, but there is no deeper environmental aspect, including land cover changes, which is contained in the analyzes presented above. Similarly, the problem of generalizing or averaging data concerns works relating to entire communes. An example can be the work of Pukowiec-Kurda and Vavrouchová (2020). Their analyzes were conducted using CLC data in 10 municipalities in the Śląskie Voivodeship (mainly the Silesian Upland). This work is very valuable, showing changes by using the index of relative change of selected land use types. The one thing is that values of the index of landscape change are shown for whole municipalities. The thus calculated variable may result from phenomena involving only a part of a municipality, and even be a continuation of the processes occurring in the neighboring municipality.

Comparing the obtained results with the works concerning other areas subject to changes in the development, we can observe that the direction of changes is not always so unfavorable. The results of the research conducted by Ciesielski and Będkowski (2014) in the Łódź Voivodeship show the desire to maintain the specific features of the area and the structural systems of villages, including the designation of land for development along the main communication routes. Also Rejter (2018) draws attention to the fact that "The differences that occur in the process of change are regional and depend on the specificity of a given region". The largest agglomerations in Poland are most often located on rivers and spread relatively evenly in all directions, obviously taking into account factors supporting this process, such as the course of main communication lines or the policy of suburban communes. Due to its seaside location, the Tri-City is characterized by slightly different possibilities of territorial expansion.

The presented approach can be used for any area: both in terms of geographic location and size of the area, with the appropriate size and shape of the mesh (squares, hexagons). The possibility of calculating the value of the indicator for different time intervals allows you to monitor changes. The method can also be used to compare the intensity of changes over a given period of time for two different study polygons, assuming that the same types of land cover and the same size and shape of the base field will be taken for the analysis. This approach is not only of cognitive value, but it also has a practical application: identifying

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conflict places in space. It is therefore a contribution to both research methods (through the use of the structure convergence index) and a contribution to the practice of spatial planning.

CONCLUSIONS

The deteriorating imbalance between biologically active and built-up areas (reflected by the changes in the land use structure) may be perceived as an indicator of the ongoing suburbanisation processes (Chart 1). It is also a key issue in terms of maintaining continuity of the environmental structure.

At the same time, the structure of land cover types in the research area is undergoing constant changes. Although the percentage of forests, grasslands and waters increased in the analysed period, still urban development is advancing and the proportion of biologically active and passive areas is decreasing. The areas where the most intense changes are observed are located in the western and southern districts of Gdańsk, in the areas southwest of Sopot and Gdańsk, west of Wejherowo, in Kępa Oksywska and Żuławy Wiślane (the Vistula delta region) – especially Sobieszewska Island (tourist infrastructure along the dune ridges) and areas east of Pruszcz Gdański. The areas where negative changes have been observed more often in the last few years include Warzenko, Chwaszczyno and Rębiechowo. The above-mentioned areas of intensive investment-related pressure should be continuously monitored and a scheme of spatial planning processes should be implemented in order to hamper the ongoing suburbanisation processes and deal with destruction of the natural environment and landscape. Taking into account the above considerations, it is concluded that the aim of the research has been achieved.

Comparing the change in the proportions between biologically active and built-up areas at different time intervals can be helpful in assessing whether changes in the landscape are conducive to sustainable development. The methods and materials used in the analysis can be applied for the analysis of other areas and for the comparison of land use changes, regardless of the adopted reference unit (for areas of different size, with appropriately selected grid). The value enumeration of the indicator of structure convergence allows to monitor changes in time and space. As highlighted in the "Discussion" section, this approach is not only of cognitive value, but it also has a practical application. It is a contribution to the methodology of landscape science and also offers the possibility of practical use in spatial planning. It is possible to use this method, for example, to indicate areas that should be under protection or for which a change of use is recommended. The analyzes of the land use changes in the long run may allow modeling of future landscape transformations.

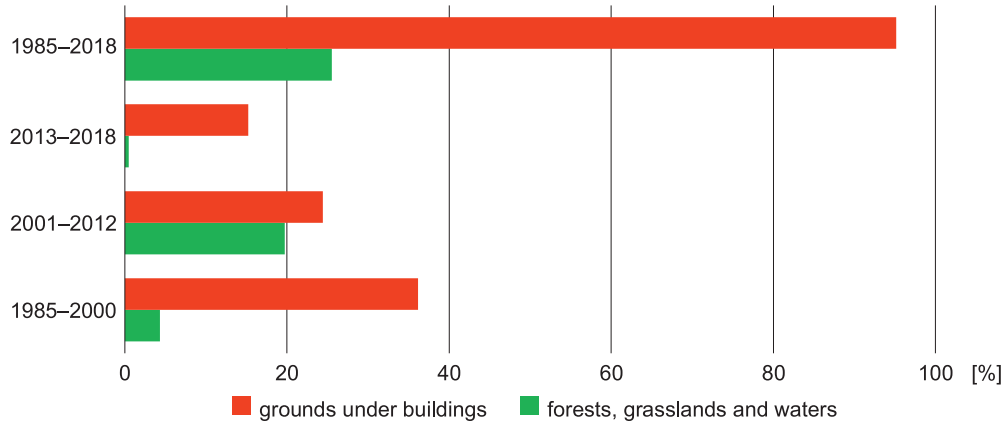

Chart 1. Changes in the structure of biologically active and passive areas in relation to the first year of a given period (%)
Source: own preparation based on Korwel-Lejkowska (2020).

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